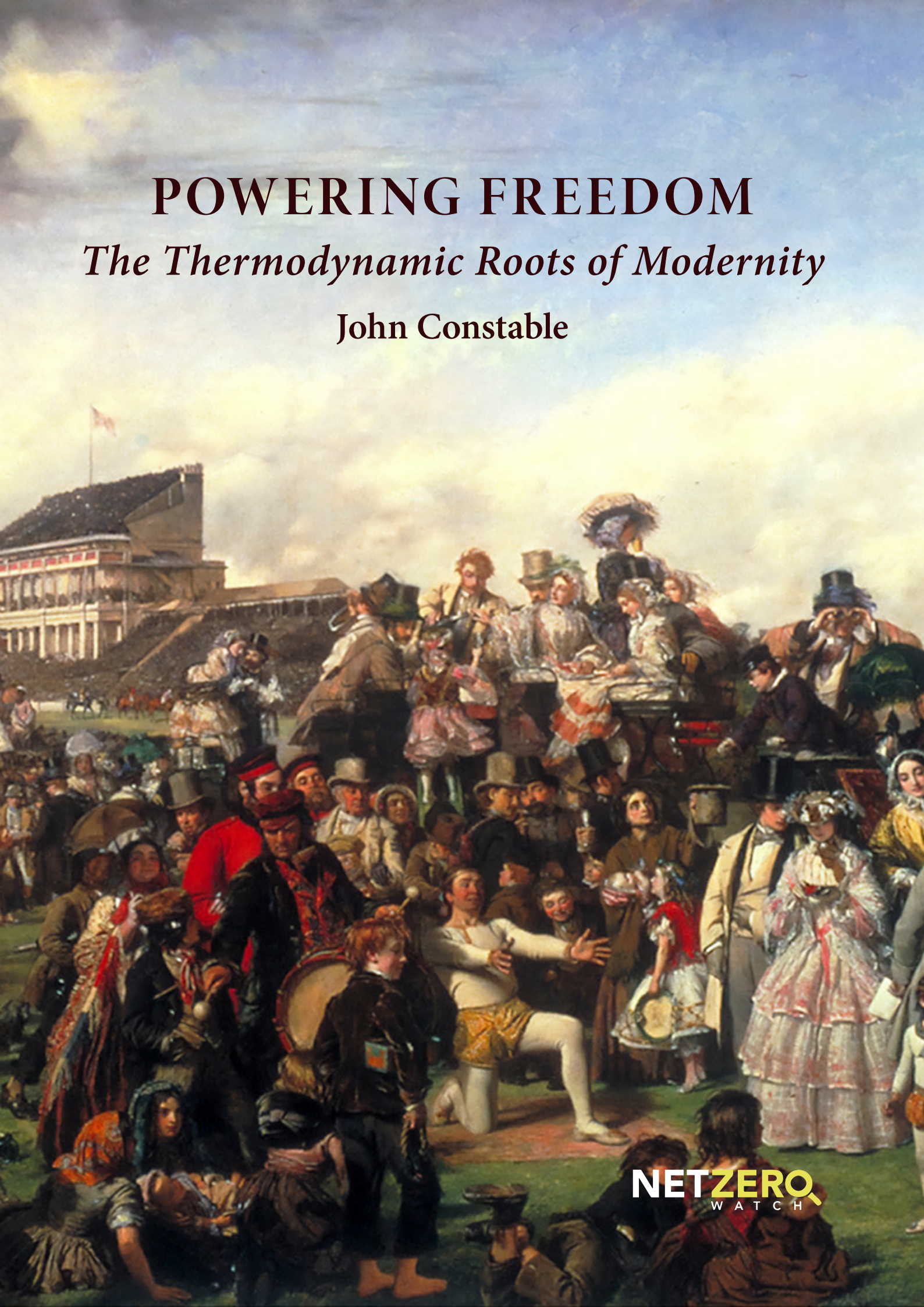
POWERING FREEDOM

The Thermodynamic Roots of Modernity

John Constable



NETZERO WATCH

Powering Freedom: The Thermodynamic Roots of Modernity

John Constable

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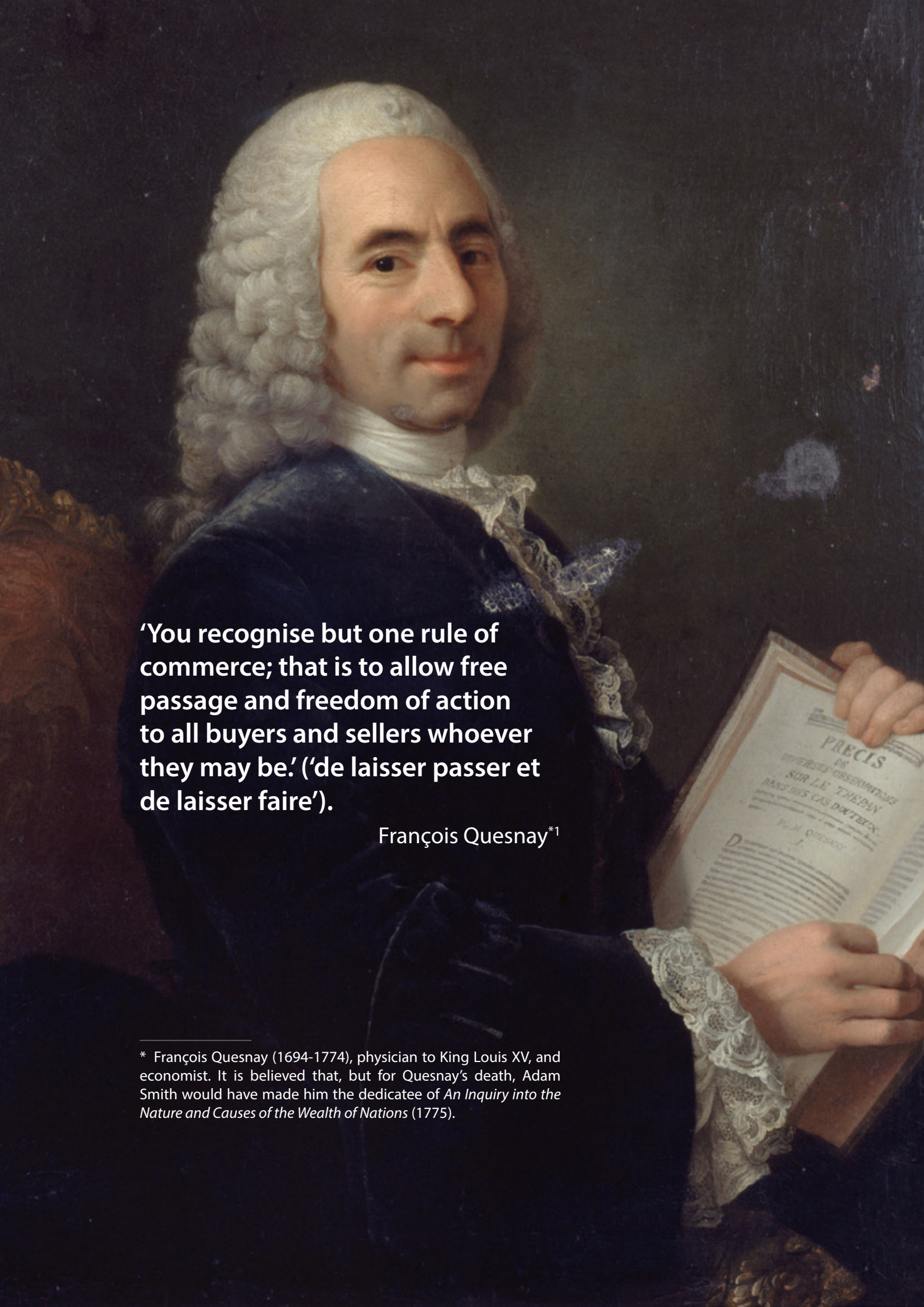
About the author

John Constable is a British academic and energy analyst, best known for arguing that the fundamental physics of fuels determines, not only their cost, but the societal structures and human freedoms that those fuels can support. Among his previous publications are *Europe's Green Experiment: A costly failure in unilateral climate policy* (2022) for GWPF, and many pieces written for Net Zero Watch whilst Energy Editor between 2016 and 2022. Dr Constable also directs the UK charity Renewable Energy Foundation.



‘You recognise but one rule of commerce; that is to allow free passage and freedom of action to all buyers and sellers whoever they may be.’ (‘de laisser passer et de laisser faire’).

François Quesnay*[1]

* François Quesnay (1694-1774), physician to King Louis XV, and economist. It is believed that, but for Quesnay’s death, Adam Smith would have made him the dedicatee of *An Inquiry into the Nature and Causes of the Wealth of Nations* (1775).

Laissez faire, laissez passer; freedom and wealth

To go where you wish and do as you wish is to be free, and with only a trivial compression this definition will cover intellectual liberty too. Travel is a subset of action, so the single term *laisser faire* is sufficient for our purposes and *laisser passer* an instance of the general category. And thought is action too, though of a kind that we find notoriously difficult to represent in terms of the structural pattern of natural science. However, perhaps we can all accept that thought in a living person requires a working brain, and that such a working brain is most certainly an intricate pattern of electrochemical action. *Laisser la penser* is an instance of *laisser faire*.

In spite of many attempts to tarnish its reputation, this principle of letting people do as they wish and go where they wish in all senses remains the noblest sentiment in political or any other kind of philosophy.

And it is a principle on which we should compromise with reluctance and only after consulting our consciences. For, however much we try to represent moral interventions as selfless, as reflecting a transcendent code, it does not require the integrity of a saint to see that the restriction of another's freedom is likely enough to fulfil a desire of our own, or to clear the field for that fulfilment. Consequently, we should accept as obvious the conclusion that any inclination to free action will conflict from time to time with the wishes of others, perhaps to some degree at all times.

As a result we must also reconcile ourselves to compromise so that we may act as freely as may be, reining in a desire to restrict the freedom of others just as we accept a limitation on our own liberty, and for the same reasons, the better to serve our own ends in the medium and longer term. We wait at the red traffic light even and perhaps especially if there is no vehicle or pedestrian to be seen, and we do so when obedience appears needless precisely because it is in our own interests that such rules are reliably upheld by all.

Of such intricate and subtle balances do we construct the world's many ramshackle and foundationless architectures of societal custom and political life, with ad hoc buttresses here and emergency cross-ties there, all to evenly share the load and reduce those occasions when stress becomes strain. There are sags and creaks, and occasional complete collapses, yet the arrangements function well enough. So much for the history and theory of normative ethics, so much for politics and political science.

But there is also a physics to these matters. For an action to be realised, the means for that realisation must be available. It is the means that makes a person free to act, and these means are in all cases necessarily physical, since the realisation of an act requires a transformation of some part of the world. I may wish to warm my room by a few degrees, and you raise no objection, but unless I have the means to raise the average velocity of the air molecules in my vicinity that wish will go unfulfilled. I may want to travel to Moscow to see Lenin face to face, but without means of transport, perhaps well-fed legs and tolerable roads, perhaps cars, planes and trains, that plan must remain unrealised and the question of whether my passport will be accepted at the border purely academic.

I would have no reflections on all such things without blood sugar to drive the biochemistry of my brain, and my thoughts would go unexpressed without the channels of speech or writing and publication and distribution. And all this requires work, many acts of work, many changes in the world. (My thanks to Net Zero Watch for their kind assistance.)

The satisfaction of wishes is axiomatically the definition of *wealth*, a point that reference to the Old English and Old Teutonic roots – 'wela', 'welon', meaning human well-being, as contrasted with 'woe' – will confirm.[2] The aggregation of many satisfied wishes produces (by definition as well as in practice) a rich, free society and all those generally public, or at least to some degree shared, benefits that arise from such a state. The frustration of human wishes, conversely, delivers a society that is poorer and more restricted in aggregate, with all the dis-

advantages both private and public that come with that condition.

On this view, economies and the populations that constitute them are statistical mechanical phenomena. Since that is the case, and no alternative has ever been successfully maintained (the City of God remains a dream), energy is far from being just one economic input amongst many. Energy is the key property of all economic inputs, and thus it determines the only thing that really matters in any economic system: namely the potential to change the world in order to satisfy human requirements: to make us free to maintain and protect our bodies and those of our offspring, to kill pathogens, to make us warmer or cooler, to move things or people here and there as we wish. In short, it enables us to broaden the human ecological niche and enhance our prosperity.

But what is energy that it should be so indispensable, and what of the fuels from which we obtain it?

Energy, fuels and fuel quality

Energy is the capacity of a piece of the natural world, by which we mean a defined segment of space-time, to resist any of the four fundamental forces: gravity, electromagnetism, or the strong and weak nuclear forces. Obviously, since mass is defined in the same way, it is equivalent to the mass of that segment of physics, a relation captured in the best-known equation in all science ($E = mc^2$). Energy, then, is the capacity to resist and overcome the fundamental forces of nature and to do work on the world, changing it.

A fuel is any segment of space-time from which we elect to obtain energy to perform a task. On this general view the world in its entirety is a potential fuel, though in practice we do not treat it in this way, since only a small fraction of the perceived environment is available or has anything close to the capacity to do the work that is required. The states of the world around us vary greatly in their ability to resist the fundamental forces, and even those that we consider sufficiently promising to designate as fuels vary enormously in their utility.

This should be obvious, but current climate policy in the United Kingdom and in much of the western world is devoted to the introduction of renewable energy – wind and solar most prominently – which suggests that differences in fuel quality are by no means widely recognised, and that the implications of these differences are barely understood at all. A clear statement of the facts seems desirable. Let us consider the various fuels that have been used by man, taking them in approximate order of their employment over history, beginning with the bodies of other organisms: biomass.

The tissues of plants, seeds, leaves, and wood, and the bodies of animals is of medium quality as a fuel, enjoying elevated energy states due to the highly improbable structure that has evolved by means of natural selection. They are of comparatively low energy density but are moderately stable over time; 'the woods decay, the woods decay and fall', as do their fruits, but not that quickly. Biomass, and the energy it contains, remains essential for human beings in the form of foodstuffs, a comestible fuel to which we are specifically adapted. It was, for a very large part of human prehistory and history, also combusted to deliver heat and light.

But biomass can be troublesome to digest or to burn, requiring processing, itself an energy consuming activity, to improve its accessibility. For example, cooking – applying heat at temperatures impossible for a human body to generate without self-damage – makes the fuel that is food more readily utilised, by breaking down organic molecules, rendering them more accessible to the chemical processes of digestion. Timber has the very desirable property of time consistency as a fuel, but it requires drying, and also logging and splitting, increasing the ratio of surface area to volume to facilitate ignition. If the timber is partially combusted and transformed by raising it to elevated temperatures in the absence of oxygen it will form charcoal, a material of nearly pure carbon, which can then be burned with oxygen to deliver still higher

and more controllable temperatures.

Biomass sources accounted for almost all human wealth before the introduction of fossil fuels in large quantities from the late medieval period onwards, and they remain important today as food even in the lives of the richest populations. (It is important, of course, to grant that the apparently naturally grown foodstuffs that support our lives are to a large degree the output of intensive agriculture made possible by diesel traction and nitrogenous fertilisers, amongst other agrochemicals, either derived directly from fossil fuels such as natural gas, or from energy-intensive chemical processes. Much of the energy in the foods of a modern society is indirectly obtained from fossil fuels.)

Wind energy is of very low quality, with little capacity to do work. Indeed, in physical terms it is close to random heat and all but useless in resisting the fundamental forces of nature so as to create improbable states of affairs in accordance with human wishes or indeed the wishes of any living creature.

Indeed, it is a remarkable fact that no living organisms use wind for metabolic energy. Birds glide on the breezes and seeds are adventitiously dispersed by them, but the energy state of moving air considered as a fuel – that is, a wind current over a relevant period – is so low that it cannot be employed to support the construction and maintenance of the extremely complicated structures that compose organic life.

The use of air currents to propel ships is limited and dependent on the ability either to wait for a favourable wind or to make use of fortunate combinations of circumstance, such as the trade winds which took ships east to west across the Atlantic at one latitude and west to east at another, or the happy pairing with a river's gravitationally driven flow that made it possible for the Egyptians to use the northerlies from the Mediterranean to carry ships up river to collect food and other goods, and the Nile's own gravitationally driven energy to return them against the winds to their ports nearer the coast.

The energy of waves, tsunamis apart, is essentially a subset of wind energy, and has, as far as I know, never been used by human beings, which is hardly surprising given the extreme difficulty of engineering to harvest its large but stochastic forces. The energy state, like wind, is on *average* low, but occasionally very high indeed, due to the density of the fluid involved. The problems presented by the time inconsistency of wind, already severe, are magnified by the involvement of water. Wave energy is not only of very low quality but highly problematic.

Tidal forces do not suffer from this problem, being predictable and only gradually fluctuating, but the average energy state over time remains low, and their utility is consequently very narrowly focused. Mariners can make use of the tides, and be much helped on their way, but this assistance is unbiddable and brief. These faults can be corrected with impoundments that capture and retain the tidal range as a head of water, to drive a mill for grinding grains for example. However, the opportunities for such schemes are limited, and their scale modest at best.

With solar energy we meet a fuel that is of high quality. The sun's radiation is unquestionably of low entropy, and its energy state is high, provided that it is gathered outside the earth's atmosphere and at a fixed distance from the sun itself. But on the surface of the Earth things are different. Seen from the perspective of a point receptor – a leaf for example, or a solar photovoltaic cell – the energy state of solar radiation over time is of low quality. There are several factors explaining this degradation in energy state. Firstly, there is a continuously varying angle of incidence, total occlusion at night, and great seasonal variation due to the precession of the globe. Secondly, suspended particles in the atmosphere diffuse the radiation (causing the sky to appear blue to our eyes), a phenomenon known as Rayleigh scattering. Thirdly, there are the random interventions of clouds, to which one might also add shadows resulting from landforms such as hills and mountains and smaller structures such as trees and shrubs.

In spite of all these disadvantages, the residual quality is sufficiently high to enable organisms to use solar radiation as a source of metabolic energy, but the creatures that do so – plants – are all but entirely devoted to over-

coming the defects of the fuel stream. That part of a plant which is not concerned with reproduction is an energy conversion and storage system, precisely adapted to managing a fuel that fluctuates in quality over all timescales, from seconds to years. The vast majority of a plant's body provides the surface area needed to collect the diffused radiation of the sun, which must take place over a very wide range of angles and orientations. Outside the equatorial regions there are seasonal periods when the radiation is at unusably low levels, and the plant's system therefore closes down and reduces its metabolic rate in order to survive until the next favourable season, living off the energy that it has accumulated when the going was good.

Considerable complexity can be created on the basis of this fuel and as we have seen it can provide a dense reliable supply to organisms that consume plants, but the characteristics of plants themselves are limited by their energy source. They have only simple sensory systems, and their ability to store information about their environment is negligible. Consequently, they are relatively inflexible in their adaptive behaviour. Plants lack integrative nervous systems, much less brains, and though they do move, this takes place on a timescale that renders it barely perceptible to high-velocity animals such as ourselves. Moreover, those organisms that ingest plants, and only plants, are themselves limited by the low density of this source of energy. Herbivores must spend most of their time grazing and they frequently possess specialised digestive systems to break down the highly resistant cell structure of plants at low temperatures.

The energy state of fossil fuels is not only high but also consistent over time. Take up a piece of coal, for example, and observe it closely over any period long or short and it will be seen to do nothing, as if it were inert and at equilibrium. However, if we supply sufficient energy to ignite it coal generates high-grade heat and short-wavelength light. Coal and the other fossil fuels are obviously very remarkable pieces of physics, and it is reasonable to ask just how this state came about.

It is a textbook and journalistic commonplace to say that coal, for example, is fossilised sunshine, or, and rather less accurately, that oil is liquefied dinosaur. There is a grain of truth in such statements, since much of the high energy state in coal, oil, or gas is, as a matter of fact, the result of natural selection delivering organic material of considerable complexity, all based on solar radiation, captured directly in the case of plants or indirectly in the case of (mostly marine) animals.

But if that were all, fossil fuels would be no better than the biomass that went into their making, and this is manifestly untrue, the temperatures readily available with these fuels being very high as a consequence of their low-entropy, energy-dense state. This extraordinary state is the result of subsequent transformation of the biomass by the operation of gravitational forces over hundreds of millions of years. Gravity is a weak force, but when the masses involved are large the aggregate energy is considerable. If I offer to place a pebble on your toe you will be unconcerned, but if I propose to bring to rest, even very gently, a hundred bricks in the same place you will correctly be alarmed.

The energies involved in the geological compression of biological material over extended periods of time to form fossil fuels are vast. Moreover, as material is compressed by the gravitational force, its entropy falls but its temperature rises – gravity is special thermodynamically – and this elevated temperature results in chemical transformations, further elevating the energy state of the substances involved. This pressure-cooking of biological material is in a sense extremely wasteful, with much of the gravitational energy being dissipated as waste heat, but that small fraction that is rendered in the dense volumes of fossil fuels makes coal, oil and natural gas remarkable physical configurations of matter. Their potential to do work is, by comparison with all those we have so far considered, quite astonishing. And this exceptional character, over and above that explained by the evolutionary ratchet storing solar radiation, is essentially to be explained as gravity. In a curious but defensible sense, the energy that drove Western Europe into sustained growth from the

1500s onwards, and still powers our economies, is ancient gravitational force.

It will be noted, however, from the examples of biomass and fossil fuels, that physical systems with high energy states are difficult to use; indeed, we might even assert that the higher the time stability and the energy state of a particular fuel the more difficult it is to employ.

Coal has a higher ignition energy than wood, and the elevated temperatures of its combustion require much more sophisticated and resistant containments. In other words, to employ high energy fuels, improbable structures of high energy state are a necessary pre-requisite, presenting a bootstrapping problem. Which brings us to the most intrinsically promising but the most difficult of our energy sources, the sub-atomic structures that we call nuclear fuels.

The exceptional character of these physical structures is both undoubted and readily explained, at least in general terms, since they are remnants of the extremely low-entropy state of the very early universe. Quite why the universe should have been in this state remains a conundrum; indeed, speaking statistically it is more likely that it was disordered in the past and for some reason has become less so, but if that were true it would make a nonsense of our memories, and be in contradiction to the observable trend, where we see that entropy tends to increase.

Thus we are driven to accept the 'past hypothesis', namely that the early stages of the universe were of very low entropy and that the entropy at the instant of the Big Bang was so inconceivably low that all the regularities currently bundled up in the generalisations we call the 'laws' of physics ceased to apply. Whether the Belgian mathematical physicist and cosmologist, Georges Lemaître (1894–1966), the founder of Big Bang theory, which he called 'The Primeval Atom Hypothesis', is right in supposing that the universe began with all its energy contained in a single quantum, or in radiation of an infinitely short wavelength, we can leave undecided for our current purposes.[3] What we can say is that the states of physics we refer to as 'normal' matter appear to have been formed from earlier and exceptionally low-entropy states, and that these succeeding states of physics are themselves still of extremely low entropy. Energy is released from them in proportion to the speed of light, meaning that a very small mass can be exchanged for a very large quantity of energy, and rapidly. These are consequently very difficult sources to use, not only because overcoming the strong and weak nuclear forces to cause rearrangements that release energy is itself difficult, but because the resulting energy is delivered at rates and at temperatures that necessitate sophisticated structures and technologies to contain and control it. We are still learning how to handle nuclear fission, the outcome of the comparatively easy cracking open of the atom and its nucleus; the successful control of the much more powerful effect of nuclear fusion for the time being eludes us.

There is no alternative except to accept as brute facts the gradients of fuel quality, and resign ourselves to living as best we can within the limits implied. But the limits are stern and unyielding. Even at their best, fuels can only be converted into work with difficulty and with losses. Marx and Engels, for all that they were materialists, baulked at the implications of thermodynamics, which seemed to present a ceiling to that state of bliss achievable in perpetuity by humankind in any political settlement, even that of perfect communism. Thermodynamics exposes as utopian all political theorists promising either unbounded progress or stable and infinite contentment. The world is not infinitely plastic in response to our wishes, and even those changes we can bring about are constantly eroded by the tendency of entropy to increase. We may no longer eat bread by the sweat of our brow, but it remains true that ceaseless work must be done somehow, and the means for that work are limited at any one time, and even at the universal level do not appear to be infinite.

Furthermore, and in a way probably not appreciated by Marx though perhaps intuited by later socialist thinkers, thermodynamics implies that it is the low quality of organic fuels, not moral deficiency in the property owning and ruling classes, that explains the structure of human society before the advent of coal. Indeed, it

suggests that, far from being conditions of unprecedented misery and an indication of coming revolution, the societies of the 19th century were characterised by widely distributed opportunity and prosperity, albeit with no guarantee of permanence.

Indeed, this paper aims to invert the view widely held amongst economists, particularly, but not only of the classical liberal strand – many socialists share this assumption – that political freedom precedes the generation of wealth. Instead, in accordance with the reasoning set out in my opening paragraphs, I shall suggest that the necessary condition for all human freedom is the possession of the means for free action, even of the humblest kind. Since action is work, the particular means required are fuels, those segments of space-time with the capacity of causing changes in the world. As we have seen, fuels vary in their ability to do work, and in their productivity, and consequently the fuels available to any society determine the levels of absolute wealth and also the distribution of that wealth over energy and non-energy sectors. Societies using low grade fuels will resemble plants, being dominated by their energy collection and storage systems, while those based on superior fuels will be able to manifest other characteristics, collecting and storing information about the world.

On this view, and bearing in mind the definition that 'wealth is an improbable physical state serving a human requirement', the whole human sphere is distant from statistical mechanical equilibrium. As a result, even the simplest human societies are very improbable states of physics. Bushmen, for example, sitting around a campfire inhabit a sphere that is remarkably well co-ordinated with their interests. They may appear poor relative to our own conditions, which may be reckoned extreme, but nevertheless a group of bushmen are far from equilibrium. They have fire, which they carry from place to place and can rekindle should it be necessary. They have relatively few tools, but these result from a long period of experiment and learning spanning multiple generations and are exquisitely well-designed for the tasks at hand and given the resources available. Hunter gatherers may lack a written language, but they have a detailed oral tradition consisting of immensely complex brain states providing geographical, meteorological and biological information, which permits them to adjust their behaviour to changing circumstances. Indeed, the niche that they inhabit is in part their own construction, and where they cannot modify their environment they have learned enough, and hold sufficient information, to enable them to modify their own behaviour adaptively.

All this is highly improbable, and implies significant energy consumption to maintain such a desirable state of affairs, particularly that inner intellectual complexity which renders them flexible and constructively responsive in the face of adversity and opportunity. That improbability is created, maintained and increased by energy conversions doing work over time, as it is in all human organisations. We carelessly say that modern societies are more energy dependent than those of the past, but this is an error. All human societies, all species in fact, are entirely energy dependent. The quantities of energy used may vary, but energy dependency is never more or less than total.

It is, however, entirely correct to note that modern societies are different from those of the past in being much more complicated – both larger and more structurally differentiated – and that this difference in complexity has arisen, not only because of an increased quantity of energy used, but because of the deployment of superior fuels: those with higher energy states, lower entropy, and a greater capacity to do work.

The organic economy and high-energy fuels

In pre-fossil economies all the improbable states of physics that comprise that society, from buildings to brain states, are generated by organic energy flows; mostly plant harvests with minor contributions from wind, and water. That is to say, these fuels generate all the wealth, the human wellbeing, all the pan-societal complexity, including the population itself. However, the energy sector – agriculture and arboriculture with some pisciculture and fishing, and a little residual hunting and gathering – is of low productivity, and consumes the bulk of its own output and uses most of the societal complexity, including the majority of the population. As a result, those who administer or have legal title to land dominate society. Conversely, the non-land sector is small and socio-politically weak.

For growth to occur, existing complexity must be maintained and further complexity added. This is difficult for any society to deliver, and for those based on organic flows of energy, such as the bushmen or the agricultural societies of the pre-coal age, it presented enormous and nearly always insuperable difficulties.

Firstly, organic energy flows are susceptible to uncontrollable variation, for example weather conditions leading to bad harvests or dearth of prey. Secondly, the accessible scale of such fuel flows is difficult to enlarge except through territorial expansion, and this objective may face obstacles either through simple lack of geographical potential or through competition with other human groups. Thirdly, because organic energy systems are of low productivity and necessarily contain most of the complexity available in that society, they also consume most of the energy they produce in energising and repairing the energy system itself. This leaves little over for other purposes, including provision against exogenous shock, such as wars, plagues, bad harvests, earthquakes, floods or other natural disasters. There is little buffer in the system. Consequently, such societies are vulnerable, and inherently unstable. It is therefore very unusual for higher levels of complexity to be maintained for long periods, let alone augmented. A run of bad harvests could wipe out societal wealth and sophistication painfully accumulated over several decades or more.

The situation with fuels of a high energy state, such as coal, is very different. They create a high productivity energy sector, and a large margin of energy over that required to sustain the sector itself. The economy can now withstand shocks, maintain its wealth, and even sustain growth for long periods.

But high productivity fuels do more than this. Because the fossil-energy sector consumes only a small fraction of its own energy output, the rest of society grows, and the energy sector experiences a relative decline in societal power. Where it was a dominant element, engrossing the bulk of societal complexity, it becomes, in spite of what may be its own absolute growth, a minority fraction.

This is societally liberating in a way that is far too little appreciated. Coal broke the power of landowners from the 16th to 19th centuries, but coal-owners did not replace them. The coal barons were indeed individually very rich, but the coal industry in aggregate was not as large a part of British national wealth as agriculture had once been. It may seem impishly controversial to describe as social revolutionaries the Duke of Northumberland, the Duke of Hamilton, the Earl of Durham, the Earl of Fitzwilliam, and the Marquess of Bute, to name but a few of the great titles associated with coal, but the energetic surplus delivered by the coal businesses from which they drew their vast incomes dwarfed the output of land and thus weakened agricultural landowners while simultaneously strengthening manufacturers, retailers and consumers. Coronets for the dukes, but caps of liberty for everyone else.

The societal transformation that is here being claimed as the result of adopting coal in the British Isles is sketched in Figure 1.

In 1550 the economy is driven almost entirely by organic energy flows, and as a result is small and dominated by its energy sector, which engrosses nearly all the wealth in the system,

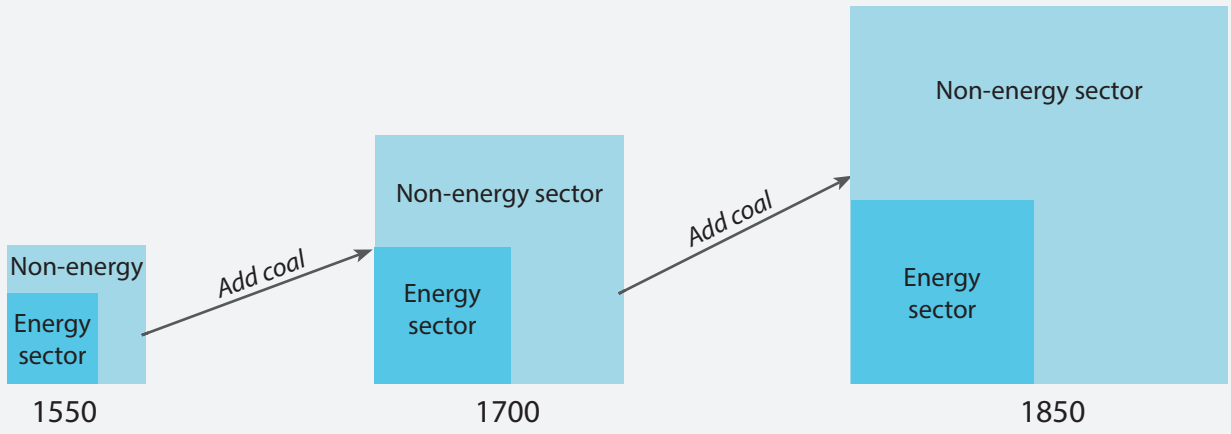


Figure 1: The societal consequences of adopting high-quality fuels.

Illustrative; not precise data. Source: Author.

with almost nothing left over for other purposes; even human reproduction is a component of the energy sector. By 1700, much coal has been added to the system, with the result that the energy producing element in the society has grown significantly, in part because agriculture has also benefitted from the cheap products of coal. But the high productivity of the coal sector has delivered a large margin of energy over that required for energy extraction, and this has delivered a substantial increase in the non-energy sector, which just predominates.

A century and a half later the economy is almost entirely driven by coal. The energy sector has grown again in absolute terms, but now represents only a minority of the total system. The vast bulk of the economy is now outside the energy sector, and society has become diverse in character, prosperous and free.

Empirical evidence illustrating this change in Britain can be found in data bearing on energy consumption, population growth, changes in occupational structure, rising industrial output, the distribution of national wealth, overwhelming military power, the rapid growth of railways, falling crime rates, and falling death rates.

Energy consumption

Figure 2 shows the annual energy consumption of England and Wales in seven representative decades, from 1561 to 1859.

The outstanding overall characteristic is very strong growth in total consumption. This was driven almost entirely by coal, which had already come to represent half of English energy supply and nearly all the growth in supply as early as 1700, long before the so-called 'English Industrial Revolution', a term which appears to be a misnomer extracted by Engels and Marx from French political economists and which was later given currency by the English social reformer Arnold Toynbee.[4] In reality the phenomenon was not solely English, being Anglo-Dutch-American from an early stage, was far from only industrial, touching every part of society, and was not a revolution in any meaningful sense of the word since it took hundreds of years and is still continuing, at least in some parts of the world, a point to which we shall return in our conclusion.

What we observe in the data is the gradual addition of coal to the system causing major but gradual changes in societal structure. Importantly, there is no 'energy transition' to be seen. Coal does not replace the muscles of men and draught animals, or the input from other sources, the use of which all expand too. Human muscular input grows as the population grows, and the availability of cheap metal made possible by coal yields benefits in all other energy sectors,

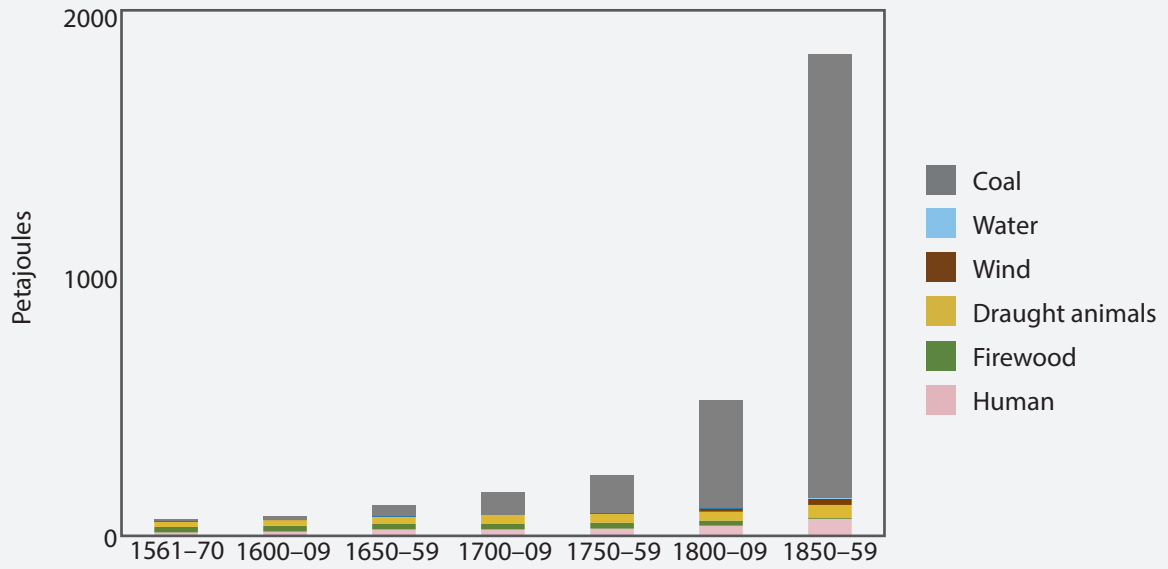


Figure 2: Annual energy consumption in England and Wales: 1560s–1850s.
Source: Data E. A. Wrigley, *Energy and the English Industrial Revolution* (Cambridge: 2011), 94.

from agriculture to water wheels and shipping. Consequently, the use of every fuel input grows, with the sole exception of firewood, which contracts in the later 18th century and all but disappears in the 19th, as cheap coal permits the economisation of wood for other purposes. In essence, rather than burning the improbable, evolved structures of trees, the elevated energy state of the molecules is employed for its engineering properties, such as elasticity and strength under compression. In a sophisticated sense this is still an energy use, though rather different from combustion.

The effects of the addition of coal are obvious. In 1550 the economy is entirely fuelled by organic energy flows, mostly solar radiation via crops, with some small contributions from mills both riverine and tidal, and from windmills and from sailing craft. The economy, and its population, are small, and the energy sector, shown by the area of the dark blue square in Figure 1, dominates society. The energy sector in this case is, of course, land. But due to the low quality of the fuel input – solar radiation – this energy sector requires most of its own production to support its activities. Almost all the capital in this society is employed on the land, and most of the production is used to feed the three quarters of the male workforce and the numerous draught animals who work it. Very little energy is left over from supporting the energy sector itself, and consequently not much can be done apart from cultivating and harvesting crops. The energy margin, the energy return on energy invested (ERoEI) as it is sometimes called, is thin, and as a result the non-energy sector, where human wishes are fulfilled, and contingency made for future emergencies, is slender.

A randomly selected child in such a system is overwhelmingly likely to be the offspring of parents working on or immediately adjacent to the land and has little chance of doing anything other than following its parents into a similar occupation. Those who own the land, the aristocracy and gentry, not only employ the bulk of the people but own the vast majority of the real, non-financial, capital in that society, the land itself, the carts, ploughs and other machinery, the livestock, and the mills that prepare the crops for human consumption, and the forests providing the wood that is the principal fuel for domestic heat, cooking and for industrial activities. The wealth and sociopolitical power of such families has rarely, if ever, been equalled in human history, and the romance of that exalted station long survived its reality; indeed it reverberates to this day, hence the persistent interest, both hostile and affectionate, in costume

drama based around country houses. The landed gentry provide an object of nostalgic fantasy for both loathers and lovers.

In reality, the power of these families was waning even in the 17th century in England, perhaps even earlier in the Netherlands where the use of peat, a very low grade proto-fossil fuel, began the process of diversifying the fuel base of the economy, and it is no accident that it is in the first years of the 18th century that we find some of the earliest complaints about the declining political power of those with land ownership and, need one add, status-assignments of title to land as compared to the rising influence of wealth unconnected with the soil. One contemporary, Jonathan Swift, the author of *Gulliver's Travels*, dated this, to him unwelcome, phenomenon to the 1690s. Writing to the poet Alexander Pope on January 10, 1721, he observed that:

> I ever abominated that scheme of politics, (now about thirty years old) of setting up a mony'd interest in opposition to the landed. For I conceived there could not be a truer maxim in our government than this, That the possessors of the soil are the best judges of what is for the advantage of the Kingdom: If others had thought the same way, Funds of Credit and South-sea Projects would neither have been felt nor heard of.[5]

Unaware of the wealth-creating power of coal, Swift attributed this change to a 'scheme of politics', a new assignment of status, rather than the gathering force of a rich and therefore liberally shifted economy progressively grounded in free contract. However, we may now conclude that it was the riches of coal that delivered liberty to the populace and enabled them to satisfy their wishes in such numbers that Bernard Mandeville's notorious *Fable of the Bees* of 1714 could wittily (and with justice) claim that 'vice' – people doing what they wished – accounted for the great public wealth of Britain.

What Swift deplored and Mandeville welcomed was the now visible diffusion of wealth and independence, consequent on the expansion of ways of life outside those supported by the land. A randomly selected child in Britain might well now live in a city, have parents who were shopkeepers or worked in trades, and far from being confined to the occupations of their mothers and fathers, could now choose between many different avenues of work. Corresponding to this diversity of employment, they also enjoyed a society in which the goods and services available were not only more numerous in character but also in volume. When there are more occupations from which an individual may choose, there will also be more kinds of wealth available to that individual as a consumer. Occupational structure is a critical indicator of human freedom and societal wealth, and fortunately there is excellent empirical information on this matter.

Diversity of employment types

The following figures, drawn from the data of E. A. Wrigley, show the transformation of British male occupational structure from 1600 to 1851. Figure 3 charts the data in terms of three high-level categories: the primary sector consisting of agriculture, mining and other producers of basic resources, the secondary sector, consisting of manufacturing and construction, for example clothing, footwear, textiles, iron and steel, and the machines and tools made from it, together with building. Finally, the tertiary sector consisting of dealers, wholesalers, retailers, and the services and the professions, including transport and communication.

In 1600 the male workforce consists of just over 1 million individuals, the vast majority, about 80%, of whom work in the primary sector, typically on the land. A century later the workforce has grown to about 1.5 million, with all that growth being accounted for by expansion in the secondary and tertiary sectors, which now account for about 50% of the working male population. This is a significant change in a relatively short time, and it explains in part one of England's great cultural changes: that between the literature and thought of the 16th century

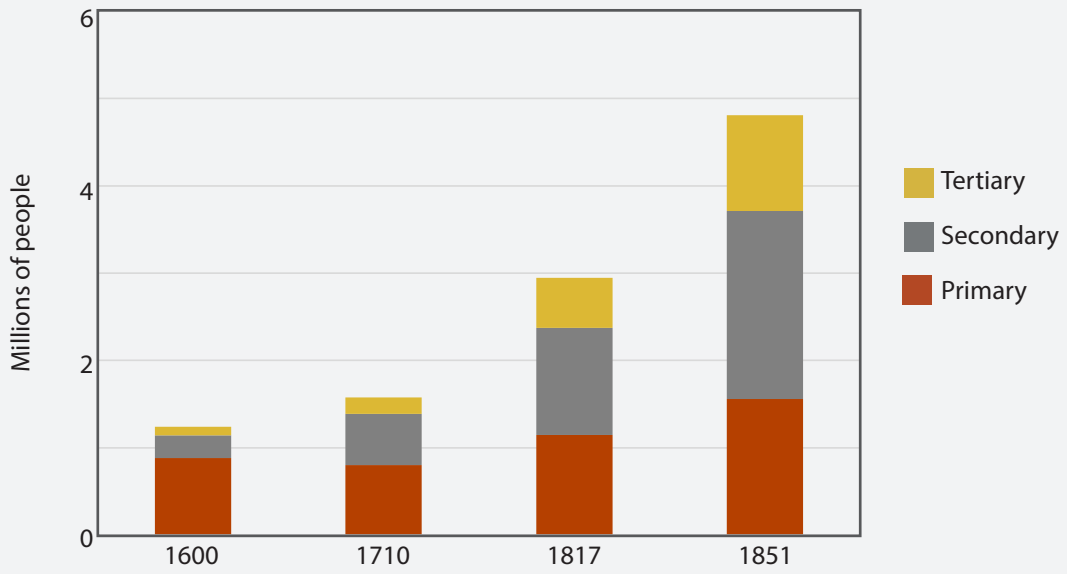


Figure 3: British male occupational structure, 1600–1851, by major sector.
Source: E. A. Wrigley, *The Path to Sustained Growth* (Cambridge, 2016), Table 5.2 (p. 71).

and that of the 17th and particularly the later 17th century. This shift presents a contrast at least as great and, in my view, much more significant than that diagnosed, largely on the basis of the misleading term 'Industrial Revolution', between the later 18th and the early 19th centuries. The 15th and much of the 16th centuries were a 'drab age' as C. S. Lewis notoriously and accurately said. That of the 17th, and particularly the later 17th century, was so vigorous and diverse that its literature can still be read with pleasure, being notably broader in its range of reference than that of the later medieval period, which rarely strays beyond the few classics then known, biblical and devotional texts, and courtly European literature. With gathering pace from 1600 onwards, English writers take the whole of their own society and indeed the whole known world as their subject. Nothing is beneath consideration or beyond their grasp, and authorship itself was no longer confined only to the university educated and the aristocracy and gentry. Many women were now both reading and writing, not least because of cheap printing and book production, itself one of the signs of growing opulence. The culture of the period serves the interests of a people now free of the land, and able to express those interests.

But this remarkable reorganisation of society was only just beginning. By 1817 the workforce had doubled to just under three million, with the second and tertiary sectors now engrossing the majority of male workers. No economy in human history had exhibited this sort of structure, and its anomaly was noted by Napoleon Bonaparte when he described England as a 'nation of shopkeepers'. These shopkeepers, however contemptible in themselves, were a manifestation of a novel and extremely powerful societal system that was capable of mobilising wealth on a scale that enabled them to contain and eventually defeat France, which, like most of the European nations, was still largely a rural organic economy, and structurally, though not politically, dominated by the land-as-energy sector. It is this comparison which underlies the otherwise paradoxical assertion of Englishmen at the time that monarchical Britain was free, when revolutionary France was not. The English were speaking not just out of partisan pride and in the interests of propaganda, though there is doubtless a little of that, but were reflecting on their lived experience. The political forms were largely irrelevant to the facts of the real socie-

ties, the real economies, and the lives of individuals within them. Irrespective of kings, bishops, lords and the gentry, English men and women could increasingly live as they pleased and go where they wished.

France, on the other hand, had the political forms of liberty, but less of the physical substance, and it is needless to add that political is less important than physical – that is to say economic – freedom. Though one might hope to live in a society enjoying both, in practice societies are frequently compelled to choose between them, and the recent and increasingly bitter experience of western democracies is that political freedom is a very poor substitute for the economic variety, whereas political constrictions, even if severe as in contemporary China, are tolerable when offset by liberty of action in the economic sphere. Napoleon had mistakenly thought England weak, and Marx was misled by the political iniquity of Victorian England into thinking that revolution was near, when in fact life as lived for a large part of the population was prosperous and the society consequently stable. By the same token we should not today mis-instruct ourselves into concluding that politically exclusive or even repressive systems are inherently weak and susceptible to decline. Our own history tells us that when combined with economic pluralism, however subterranean, they can be long lasting and powerful.

The origin of this English societal transformation, so puzzling to contemporaries like Swift and to succeeding generations, was simply the productivity of the coal mining sector, a point that we can bring out by recharting the male occupational data but at a higher degree of resolution. In Figure 4 the colour scheme used in Figure 3 has been retained, with the primary sector indicated by red, the secondary sector by grey, and the tertiary with yellow, but with those categories broken down into their components and indicated by shades of the relevant colour.

Commenting on this data, Wrigley writes:

> Whereas in Tudor times agriculture employed about three-quarters of the workforce, by the early eighteenth century the comparable figure was only one half, and in the course of the eighteenth century it declined further; in 1800 it was less than two-fifths.

As a result, other types of employment increased significantly; Wrigley continues:

> Secondary and tertiary employment more than doubled its share of those in employment, and, since the population of the country also more than doubled, the absolute size of the non-agricultural labour force by the end of the 18th cen-

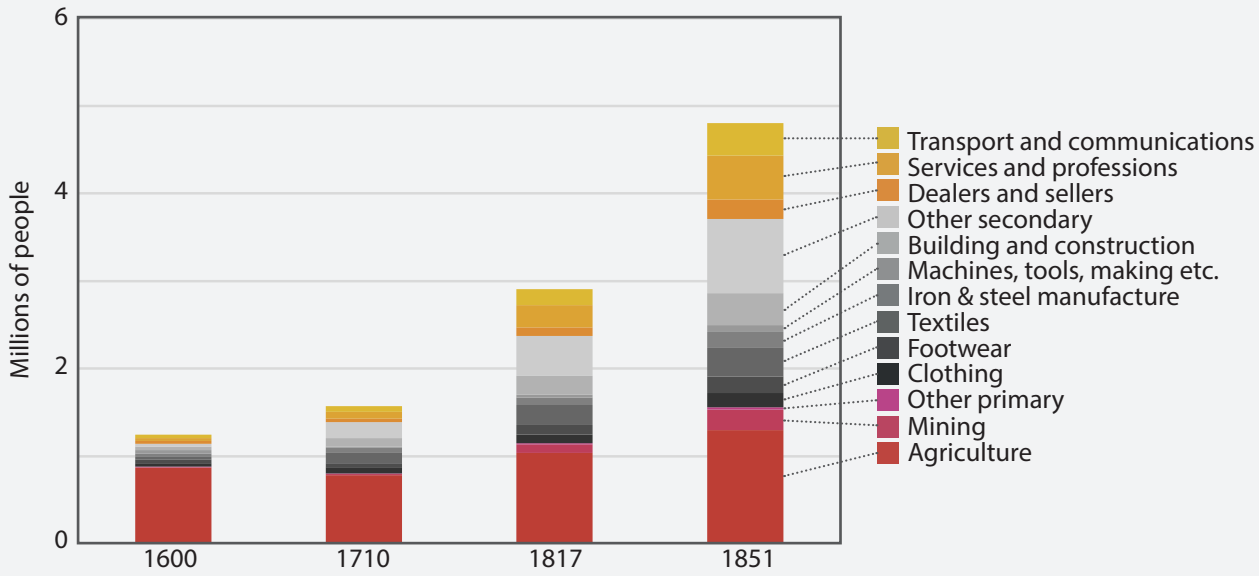


Figure 4: British male occupational structure, 1600–1851, by major and minor sector.

Source: E. A. Wrigley, *The Path to Sustained Growth* (Cambridge, 2016), Table 5.2 (p. 71).

tury had soared to at least four times its number at the end of the 16th century.[6]

This startling change was driven by the small fraction of the total workforce that was employed in coal mining. Although only a minority even of the primary sector, it was the output of coal miners that drove the large increase in total energy supply and thus facilitated the growth in the secondary and tertiary sectors. This should be recalled when reading claims by today's wind and solar industries, or indeed by government, that the green economy will create great numbers of jobs. Even if true, and it is reasonable to suspect that most of the work created will be in low-cost Asia, not the United Kingdom, this is undesirable. A high-productivity energy sector employs relatively few people, though at high wages, but creates a flood of employment in the wider economy. A low-productivity energy sector, such as that inevitable in the case of renewables, may employ more people, and probably at lower wages, but it will be unable to support employment in the wider non-energy (secondary and tertiary) sectors. It would appear logical to reason that a renewable energy transition, if achievable, would reverse the structural transformation of the coal age, from the 1600s to the 1800s, a point to which we shall return in due course.

Population growth

As is implicit in the male occupational data, the English population was growing significantly from the 1500s to the later 1800s, and quinquennial data is now available permitting examination in relation to exogenous shocks such as plagues and bad harvests. Figure 5 charts population growth, and indicates four great plagues of the 16th and 17th centuries, and eight periods of bad harvests extending over several consecutive years.

As can be seen, population approximately doubled between the 1540s and 1700, with minor perturbations in the upward trend correlated with plagues and bad harvests. Indeed, bad harvests continued to have some effect on population growth well into the 18th century. However, perhaps the most notable run of bad harvests depressing agricultural output occurred in the period 1795 to 1819, yet it had almost no effect on population growth. England was by this time so rich that it was able to ride through such shocks and at the same time fight a widespread war to a successful conclusion.

Overall, the rising trend of human popula-

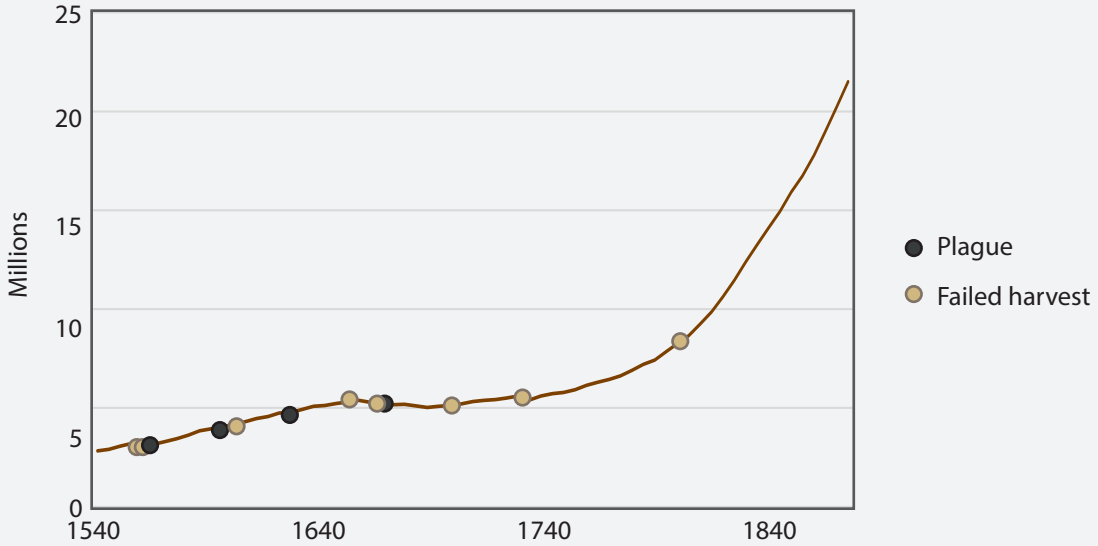


Figure 5: English population, plague and dearth 1541–1871.

Source E. A. Wrigley, et al., ***English Population from Family Reconstitution*** (Cambridge, 1997), Appendix 9; Plague and harvest data from other sources.

tion is closely correlated with both rising energy consumption, and industrial output (discussed below), making it plausible in my opinion to argue what is already evident from biological theory, namely that offspring can be regarded as the ultimate output of an economy.

Urbanisation

In addition to growing, the population was also, to an historically unprecedented degree, urbanising, as can be seen in Figure 6.

Commenting on this phenomenon, Wrigley reports that in the 16th century only 5% of the English population lived in towns of 5,000 or more inhabitants; but by 1800 this figure had risen to more than 25%, making England one of the most heavily urbanised of all European countries.[7] This is all the more striking since Europe was actually more urbanised in 1600, at 8%, a level that had only risen to 11% in 1800. The socio-political impact of these changes cannot be underestimated: *Stadtluft macht frei*: the air of cities makes you free.

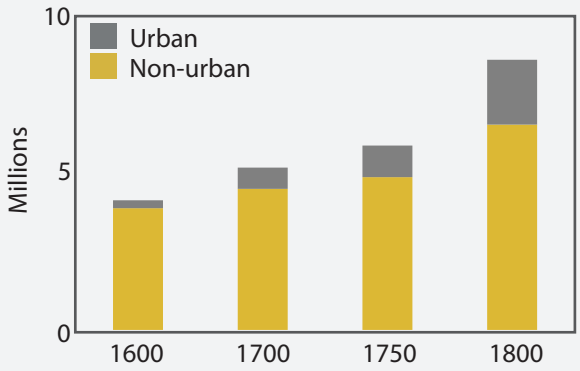


Figure 6: English population and urbanisation 1600–1800.

Source: E. A. Wrigley, *The Path to Sustained Growth* (Cambridge: 2016), Table 4.1 (p. 47).

Falling crime

Humans are sexually reproducing, competitive organisms, less driven by absolute than by relative levels of wealth. Conflicts of interest are consequently ubiquitous and unceasing, and all games are zero sum in the longest run. But in conditions where the available ecological niche is expanding, the pool of wealth from which all drink broadening and deepening, interpersonal friction can be reduced if not quite suspended. That this occurred in Victorian Britain is all the more remarkable given the increase in population (see Figure 5). The occurrence of crime may be taken as a convenient proxy for such friction, and committals to magistrates' courts as a fair indicator of levels of criminal behaviour, these being cases where the crime was sufficiently serious and well-evidenced that officers of the law were willing and able to put the matter before

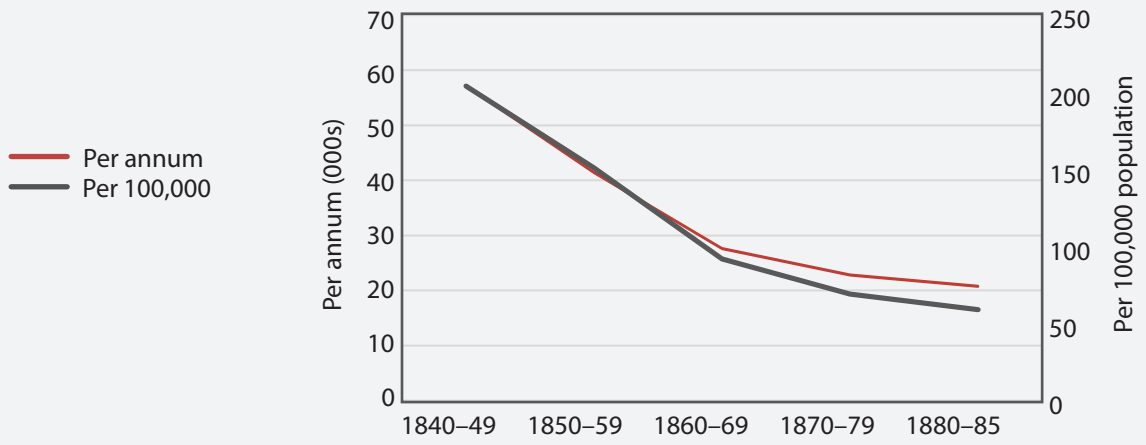


Figure 7: Committals to magistrates' courts 1840–1885.

Source: Michael G. Mulhall, *Fifty Years of National Progress: 1837–1887* (1887), 91.

at least the lowest level of the judiciary. As Figure 7 indicates, there was a significant decline in total committals during the 19th century, falling from just under 60,000 a year in the 1840s to just over 20,000 a year in the 1880s, in spite of that rising population. Indeed, between those two dates their frequency fell from about 200 to just over 50 per 100,000 of population.

Falling death rates

Rising population is in itself strong evidence of improvements in the general health of the British population, but there is also suggestive data from the latter half of the 19th century relating to death rates per million of population (Figure 8).

Around 1850, death rates exceeded 22,000 per million, but this fell to about 17,000 per million by the last years of the century, with the trend continuing so that by the 1970s it had fallen to about 5,000 per million.

The data presented here is analysed by cause, and we can see that the latter half of the 19th century saw substantial falls in deaths caused by water and foodborne diseases and other conditions attributable to microorganisms, with a significant reduction in airborne diseases. One might expect this outcome since the improvements in living conditions delivered by increased energy consumption would most directly and rapidly have positive consequences in the cleanliness of food and water supply, with a lesser but important effect on lethal airborne infection through improved nourishment leading to better general health.

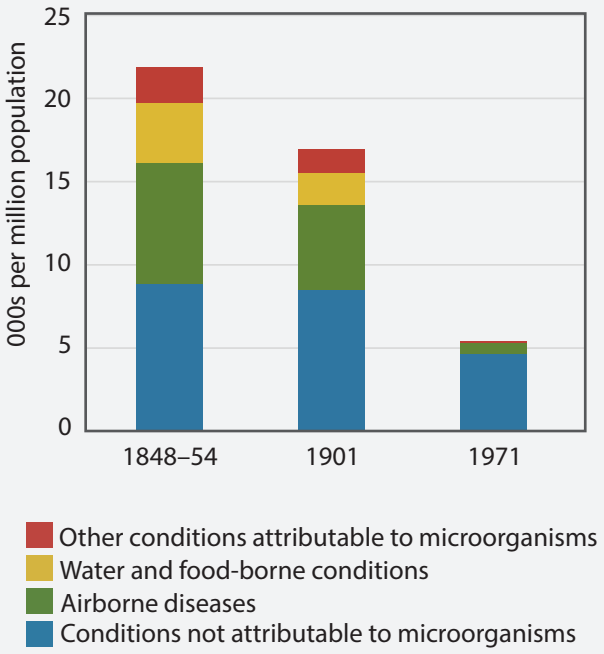


Figure 8: Disease death rates by cause, 1848–1971.

Data: Corrected from McKeown (1976) in Bernard Harris, 'Health and Welfare', in R. Floud, et al., eds, ***The Cambridge Economic History of Modern Britain***, Vol II, 1870 to the Present (Cambridge: 2014), 132.

Rising industrial output and the distribution of wealth

As is well-known, British industrial output rose very sharply from the 1600s to the latter part of the 19th century (Figure 9).

While the growth compounding effect appears to be stabilising in the later 1400s, perhaps due to the undoubted improvements in agricultural productivity, it is worth emphasising that output is more erratic before coal became a predominant part of the energy supply in the later 17th century, probably because human labour was a principal component of output in the organic system, and could be affected by pandemics. By the 17th century, even a return of the plague, which had caused a substantial and sustained reduction in aggregate output after the Black Death in 1348, could only perturb the upward trend, not cause a reversal. By the later 18th century and the 19th century human labour was a decreasingly important factor in the creation of wealth, which was then, as now, largely the result of systemic, mechanical factors. Indeed, I am inclined to interpret the rise of socialism over the century and half 1750 to 1900 as a response to the falling value of labour in the

Figure 9: British industrial output, 1270–1870.

1700 =100, log scale. Source: Redrawn from S. Broadberry, et al., ***British Economic Growth 1270–1870*** (2015), 136.

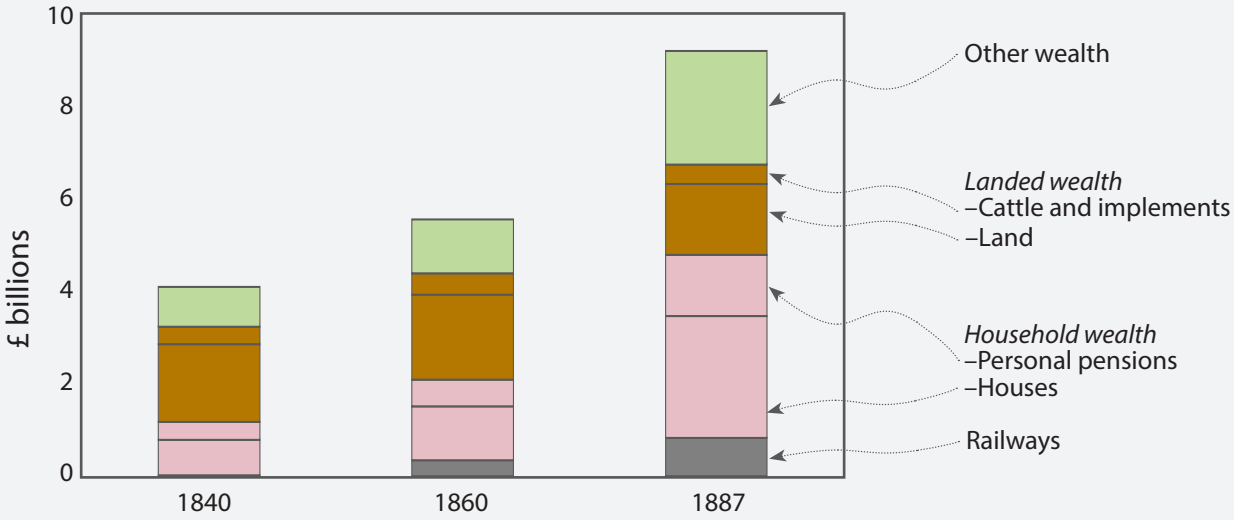


Figure 10: Increasing British national wealth: 1840–1887.

Other wealth consists of shipping, merchandise, bullion and sundries.
Data: M.G. Mulhall, *Fifty Years of National Progress: 1837–1887* (1887), 17.

presence of coal, socialism being an attempt to assign through *status* and right those incomes that labour could no longer obtain through freely negotiated *contract* (to use Maine's suggestive terms).[8] Partly because of the success of that campaign, and partly because labour was not yet quite valueless, wealth in the broadest sense was as a matter of fact increasingly evenly distributed over the population, as can be seen in Figure 10. In 1840 landed proprietors, in brown, still accounted for the bulk of national wealth, with households, in pink, enjoying a substantial but minority share. Within twenty years this aggregate national wealth had increased by over 40% but household wealth had almost doubled, and by the end of the century household wealth accounted for nearly half of national wealth. In the fifty-year period charted here, 1840 to 1887, household wealth increased fourfold, and the aggregate wealth of the landed sector actually declined in absolute terms.

Travel and transportation

Figure 10 also indicates a rapid growth in the wealth constituted in the physical capital of railways, this rising from nothing in 1840 to just under £1 billion in 1887; about 10% of national wealth on this estimate. The importance of this development is hard to overstate; the freedom to travel from one place to another at will being for most an indispensable element in any liberty worth the name. We may try to take consolation in the thought that 'stone walls do not a prison make, nor iron bars a cage', but in reality that poetical proposition puts a brave face on a horror that most would avoid at all costs.

But the fundamental impediments to free movement are not legal or political, but crudely physical. Translating our own bodies or some object from one location to another entails overcoming both the inertia of the mass to be moved and the force of gravity and the consequent friction that results as one mass moves over another. Energy is obviously required, and the relocation of the moved object is a clear type specimen of the definition of wealth with which we began this discussion. It is an improbable state of affairs in accordance with a human wish.

Evidence of free movement is, then, an important, indeed a defining metric of both wealth and liberty, and the introduction of coal had remarkable effects on this matter long before the development of the steam railway. Cheaper heat and mechanical energy, and thus lower-cost metals, lie in part behind the improvement in the state of British roads – which at an abstract level are smooth surfaces reducing the co-efficient of friction – and of horsedrawn transport. Indeed, contemporaries such as de Quincey, looking back over the period in 1849, pointed not to steam as the principal index of British power and modernity but to the rapid transit of people and messages made possible by improved roads and the intricately administered and reliably timetabled horse-drawn mail coach network that operated over them.[9]

But important though this was, growth in the railways was by any metric more significant. Figure 11 records the growth in miles of railway and millions of passengers in Britain between 1840 and 1885. At the beginning of this period the length of track and the number of passengers carried per year was effectively zero. By 1885 there were just under 20,000 miles of track, over which some 20 million passengers a year were travelling.

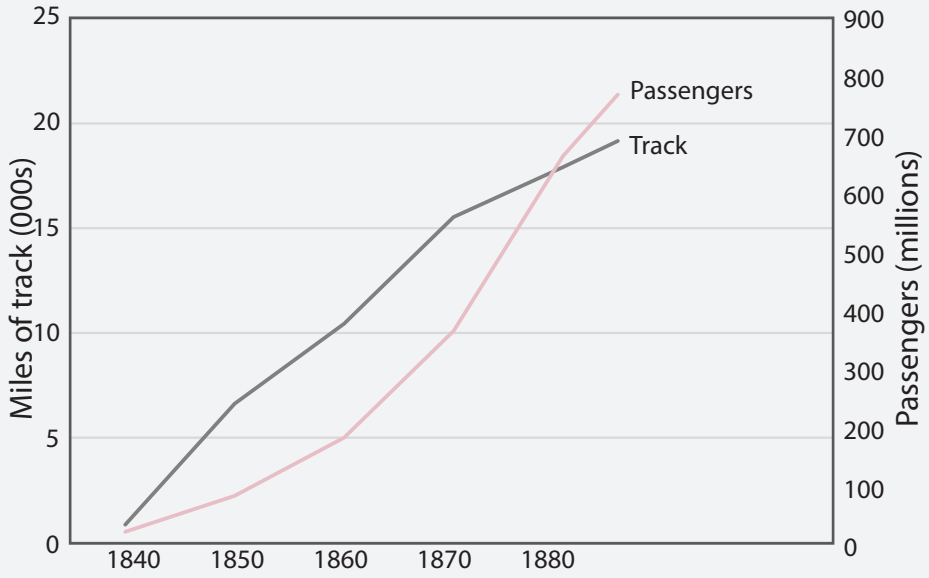


Figure 11: Miles of British railway, millions of passengers per year: 1840–1885.

Source: Michael G. Mulhall, *Fifty Years of National Progress: 1837–1887* (1887), 18.

Projected force: imposing will on others

As we have seen, by 1700 Great Britain was an economy quite different from any other, contemporary or historical, deriving 50% of its energy from the thermodynamically superior fuel of coal. The population was larger, healthier, more mobile, richer at every level, and had a wider choice of employments than ever before, in that or indeed any other country. The English could, increasingly, do what they wanted and go where they wanted.

This immense wealth also manifested itself as the capacity to project force and to impose the will of the British people on other populations. This too is an aspect of liberty, perhaps one we are ashamed to discuss, but not to be forgotten as a human reality.

It is important to note once more that this great power became evident early, long before the misdescribed 'Industrial Revolution'. In 1704 the British army, hardly seen on the continent for several hundred years, moved some 16,000 troops 650 miles from London to Blindheim (Blenheim) in Bavaria, picking up some 24,000 allies *en route*, and paying for supplies in cash at every stage, so good was the credit of the London government. The logistics of the British general, the Duke of Marlborough, were impeccable, with new boots for the entire army as they entered Bavaria. Facing them was the leading continental force, that of France, and its local ally. The two sides were roughly matched, at 40,000 men each, but Marlborough's victory was complete, with the entire Franco-Bavarian army being overcome and dispersed, and the French commander Marshall Tallard and his entire staff ignominiously captured. Perhaps still more remarkable, Marlborough was able to gather his forces in good order and return to England without let or hindrance. It was an extraordinary performance and stunned Europe.

And at sea this remarkable physical power was if anything even more marked. Figure 12 shows the *Royal Sovereign,* a first rate, 100-gun warship of the Blenheim period.

Such a ship is a vastly improbable structure, indeed one of the most complicated ever manufactured by man, a fact well understood by contemporaries such as the proto-economist and social philosopher Bernard Mandeville, who wrote in 1729 that:

> In bulk and weight [a warship] is vastly superior to any other moveable body of human invention, so there is no other that has an equal variety of differently surprising contrivances to boast of.[10]

Not only were these ships large and complicated, but their weaponry was formidable. As the naval historian Andrew Lambert remarks of Royal Sovereign, Britannia and Victory, they were simply 'colossal', with each having 'more firepower than the entire Russian Army'.[11] No ruler with a coastal city would want one of these vessels anywhere near it if hostile.

Military capacity of this order was novel, and its disturbing influence in Europe immense. The productive power of their peat and coal-fuelled economies permitted both the Dutch and the English to resist the great Catholic family of monarchies, all of which were grounded in the status arrangements of medieval organic, land-based society. England overthrew its kings in three phases, firstly as the English monarchy itself resisted the papacy, Henry VIII and his daughter Elizabeth creating their own Protestant church. In the second phase the king, Charles I, was overthrown and executed in 1649. But the Commonwealth that was attempted did not succeed, and in the third phase the monarchy was restored in a much weakened Protestant form in 1660. However, both Charles II and James II hankered after the absolutist past and James, lacking his brother's patience and guile, attempted to reverse the trend. His humiliating failure resulted in a further reduction in monarchical power at the Glorious Revolution of 1688.

The Dutch path passed through a series of bitter wars that brought them at first into conflict, not only with their overlord the Spanish Catholic monarch, breaking that authority, but also with their neighbour England. This latter conflict was resolved when England and the Netherlands were brought under the same limited monarchy in 1688, and thus came into

Figure 12: The Royal Sovereign 1701.

L. De Man ca. 1725

conflict with the remaining major Catholic empire, France, a struggle that resulted, though did not end, in the devastating defeat for France at Blindheim.

The effect of these Anglo-Dutch victories on both the Spanish and French systems cannot be overstated, with their actual power greatly weakened and the self-respect for their internal social organisation undermined, a fact that left Spain a burned-out shell, and France one of the most politically discontented populations in Europe. The English nobleman Lord Chesterfield wrote in 1753 that 'The French nation reasons freely, which they never did before, upon matters of religion and government, and begin to be *spregiudicati* [uninhibited in the expression of opinion]; the officers do so too; in short, all the symptoms which I have ever met with in history, previous to great changes and revolutions in Government, now exist, and daily increase in France.'[12] The revolution, a genuine revolution in this instance, would not come for some time, but the underlying causes were present in the 1750s, and had roots still further back in the failures of the early 1700s.

Meanwhile, the socio-political liberty that grew as a consequence of fossil-fuelled liberty in the Netherlands and in England rendered them amongst the most politically tolerant and contract-shifted states in history. This led British colonists in the Americas to attempt the design of an entirely new political system in 1776, an example that stimulated the already excited French system, resulting in the revolution of 1789. To the north the nationalism of Fichte and List, the latter being deeply interested in and an authority on the British and the American economies,[13] steadily eroded the legitimacy of the disparate Catholic and Protestant princes of the German-speaking region of central Europe, these states eventually coalescing in 1870. The French and the German transformations were not only inspired by the example of British and American freedom, or rather Anglo-Dutch freedom as manifested in the Americas, but by the immense and novel power of these states. However, rather than emulating the political structures of their opponents, both France and Germany became centralised authoritarian systems in order to adopt the new fuels and deliver effective powers of defence and offence.

In essence, without the Anglo-Dutch transformation, there would have been no American Revolution, and without the American Revolution no French Revolution (or at least something very different), and without the French Revolution no German unification (or at least something very different). Indeed, the emergence of those modern nation states, as distinct from the amorphous, agrarian Catholic empires, the last example of which died in the Austro-Hungarian network, can be seen as a consequence of the adoption of peat and coal in the Anglo-Dutch and American economies. Freedom, like the whirligig of time, brings in his revenges.

Imposing low-quality fuels on a complex system

We have seen that, as a consequence of adopting fuels of low entropy and a high-energy state, Britain (and the Netherlands and North America) moved rapidly away from thermodynamic equilibrium, becoming vastly more complex. For the first time in history, economic growth was sustained, and robust in the presence of exogenous shock. British society in particular experienced extraordinary increases of industrial output, a growing and urbanising population, an unprecedented expansion of non-agricultural occupational types, larger and cheaper transport networks, increasing household wealth, growing personal wealth, falling crime, declining death rates, and vast geopolitical power. National wealth was not only larger in aggregate but more evenly distributed over the entire population. Landowners lost effective societal power, but coal producers did not replace them, and there were large gains in personal freedom for the whole population. Inevitably, politics was transformed, and the general trend of progressive liberalisation and democratisation in Britain from 1600 to 1900 can be read,

and I suggest has to be read, as a reflection of the fact of real physical liberty. Wealth – that is, physical freedom – precedes political freedom. Indeed, political freedom is an output of a physically free society, not its fundamental cause. It is of course quite true to say that political freedoms further enhance the wealth-creating potential of an adequately fuelled society, resulting in autocatalysis, but political freedom in itself is neither necessary nor sufficient to deliver wealth; both France and Germany resorted to authoritarian systems for a reason. Low-entropy fuels on the other hand are both necessary and sufficient. Political freedom is only a possible outcome of a wealthy economy – that is to say, a physically free society – not an inevitable one. What *is* inevitable is that, should the fuelling of an economy be disrupted, and low-quality fuels substituted for those of high quality, both physical and then political freedom, if any, will decline. The exact trajectory of this transformation is something on which we can only speculate, but enough is known about the effects of introducing coal on British societal structure for us to sketch the broad outlines of its reverse, and Figure 13 thus employs the same schematic forms as those used above in Figure 1.

The diagrams begin with a developed, industrialised economy in about the year 2000, which exhibits the basic structure that has obtained since the 19th century, with an energy sector that is so highly productive that it is dwarfed by the non-energy economy that it creates. Policies are then introduced to coerce the economy to adopt high-entropy, low energy-state fuels, with the ambition of achieving Net Zero emissions. There is no essential connection between low emissions and high entropy fuels, but policy has in fact and mistakenly selected wind and solar for the purposes of decarbonisation, and this choice is adopted in the model. The result of this coercion is twofold. Firstly, capital migrates into the energy sector to secure the subsidised incomes and coerced market shares that are offered by policy. The energy sector therefore grows. However, because it is less productive than the fossil fuel system it is displacing, the cost of energy rises and energy consumption starts to decline, and the overall economy begins to contract. The combined effect is that the non-energy sector of the economy shrinks relative to the energy sector, restricting human physical freedom.

Up to this point I am reasonably confident in the accuracy of the cartoon; indeed, it is, as I shall show in a later section, consistent with empirical evidence from the western economies. The third panel is speculative. It is assumed, which I trust will not be the case, that in spite of severe reductions in human welfare, governments persist for another fifty years in coercing the adoption of wind and solar. Hith-

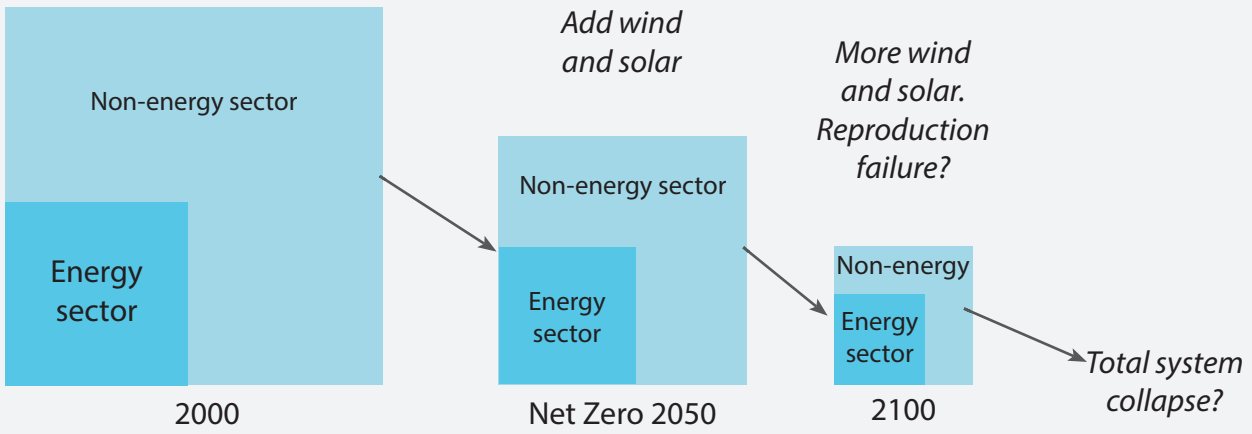


Figure 13: The probable consequences of coercing the introduction of low-quality fuels.
Approximate and speculative diagrams, not precise data. Source: Author conjecture.

erto, the wind and solar industries have been in effect parasitic on the high productivity of the residual fossil fuelled system; indeed, wind and solar fuelled generators and other ancillary equipment needed to operate them, such as inverters and batteries, are an output of the fossil economy and therefore apparently affordable. With that support the renewable energy sector was able to grow, even though the overall economy was suffering contraction. However, this situation cannot persist for long, since as the fossil industries are driven out of the economy the renewables industries must rely on their own output to repair and refresh their capital equipment. Due to the low productivity of the system, it is not possible for a renewable system to simultaneously supply its own energy sector needs and those of the wider economy around it. Thus the energy system and the wider economy are in competition for resources, with neither being adequately fuelled. The energy sector therefore suffers reproduction failure – the energy sector cannot refresh its own capital – and starts to contract. The non-energy sector is driven to an extremely low level and terrible human suffering presumably results. If corrective action is not taken, or is impossible, then total system collapse might result, though it is just conceivable that the economy might restabilise in a form resembling the agricultural economies of the past, with a much smaller population, a much restricted human sphere, and a dominant energy sector. Aggregate human wealth would be small, and the society would once more be vulnerable to exogenous shocks. Levels of freedom, as we have defined them, would be once more very low indeed.

While I am prepared to defend this general account in structural terms, the timeline suggested is conjectural. I have assumed a decline that is nearly as gentle as the ascent which we have traced in the historical data from 1600 onwards. But this is far from certain. It is well known that complex systems tend to be stable only under the condition of expansion, and it is therefore conceivable that the onset and pace of reproduction failure could be rather more rapid than that assumed in my model. One climbs slowly but falls fast.

While it is not my purpose here to do more than describe the relationship between high-quality fuels and human flourishing and freedom, and to warn against the coercion of the modern energy system in a retrograde direction, it would be negligent to leave the reader with the impression that this is a merely theoretical concern. As indicated above, there is data to suggest that the second of the two panels in my cartoon is an accurate description of the current situation, and it is with this material that I shall close.

Falling energy consumption in the West

At a general or global level, energy consumption seems to be increasing (Figure 14). Other things being equal, more energy consumed will indicate a human sphere that is moving away from equilibrium, and towards a condition that is more favourable to human beings. The niche is expanding.† But not all economies exhibit this global trend. Indeed, western economies show signs of deep perturbation, with the United Kingdom, for example, exhibiting a startling decline in energy use since 2005 when climate policy costs became salient (Figure 15). British electricity consumption, perhaps an even more important indicator, has fallen by about 23% since 2005 (Figure 16).

The British experience is an extreme example, but many countries in Europe exhibit similar disturbances, the exceptions tending to be those, such as Poland, which have retained a very large fossil-fuel share, or those that have

† In passing, we should note that this chart gives the lie to claims of a global energy transition. Total renewable energy, of all kinds from solar photovoltaic to 'traditional biomass' in the developing world, constituted 13% of global supply in 1971. In 2022 it supplied 14%, having barely kept up with the overall increase in energy consumption that has approximately trebled total supply, supporting historically unprecedented populations enjoying levels of wellbeing and freedom exceeding the wildest dreams of previous generations.

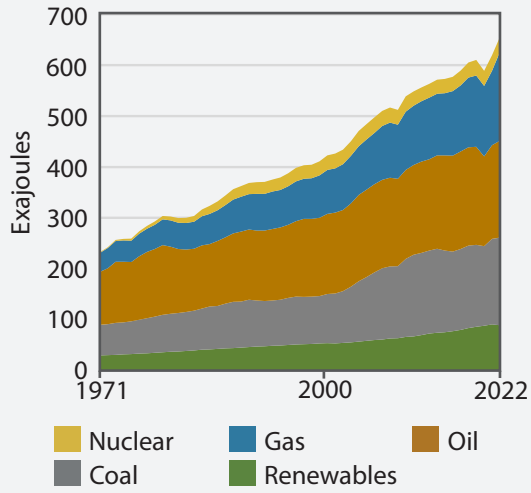


Figure 14: World total primary energy supply, 1971-2022.

Data: International Energy Agency.

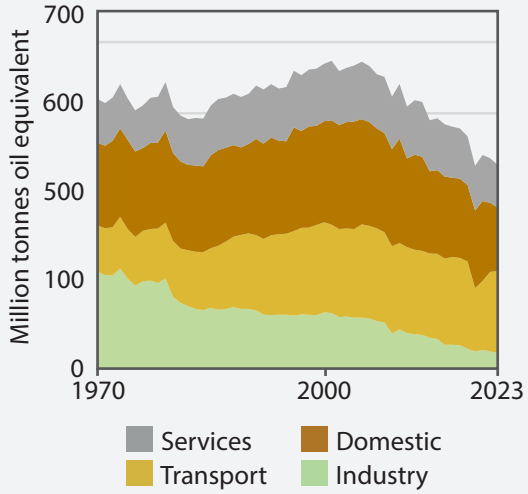


Figure 15: UK primary energy consumption by sector, 1970–2023.

Data: Department of Energy Security and Net Zero.

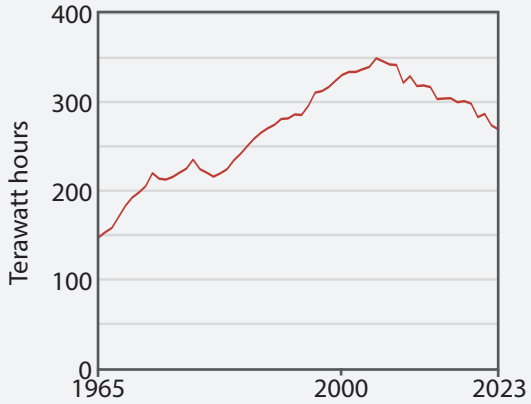


Figure 16: GB electricity consumption, 1965–2023.

Data: Department of Energy Security and Net Zero.

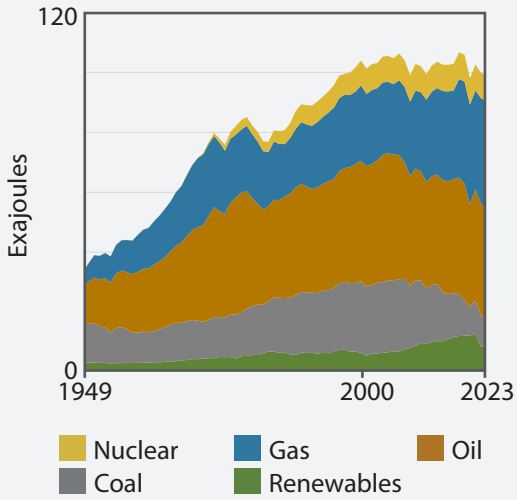


Figure 17: US total primary energy, 1949–2023.

Data: US Energy Information Administration.

developed and retained significant nuclear capacity. Wherever climate policies have relied heavily on the penalisation of fossil fuels, and the subsidisation of renewable energy, particularly wind and solar, energy consumption will be found to be either stalling or falling, and this is true even in the United States (Figure 17).

Indeed, if we focus on American industrial energy consumption we find indications of fundamental weakness (Figure 18). In 1990 the People's Republic of China was using less energy in manufacturing than the United States, but as of 2019, the last year for which comparative data is available, it was using between three and four times as much, and is on a rising overall trend, with an increasing share of electricity, whereas American industry is on a declining trend and appears to be de-electrifying. Competition with the fossil-fuelled economy of China has driven America out of manufacturing in general and, since electrically driven processes are associated with precision engineering, into cruder forms of manufacturing.

It will seem reasonable to some to ask whether the explanation of this documented reduction in energy use, in the UK and the US, results

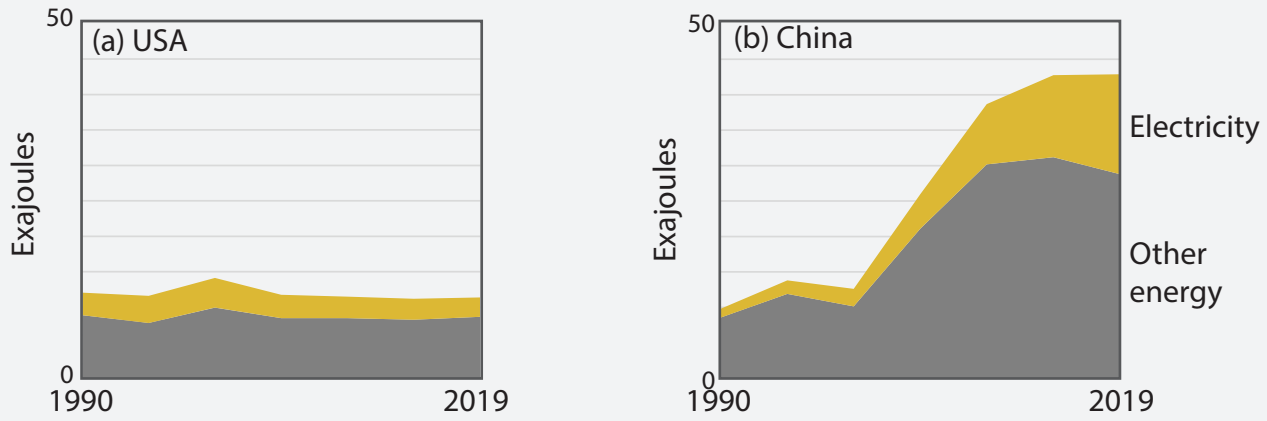


Figure 18: Industrial energy consumption in China and the USA, 1990–2019, by fuel type (non-electricity and electricity).

Source: Calculated from International Energy Agency (IEA) data.

from energy efficiency. However, we can dismiss this suggestion as a simple conceptual error. Efficiency and conservation are entirely distinct concepts, and it is, as W. S. Jevons wrote in 1865:

> …wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption.

Indeed, as Jevons went on to explain:

> The very contrary is the truth. As a rule, new modes of economy will lead to an increase of consumption.[14]

Nothing has changed in the intervening century and a half, and his contention remains robust. The literature on Jevons' observation is now large, and many refinements have been proposed, mostly concerning short-run or localised effects, but nothing has been produced to controvert the fundamental logic of his position as it applies to the macro-economy over time, which is not only brilliantly reasoned but entirely free of the wishful thinking that clouds the majority of the subsequent analysis. Indeed, anyone attempting to form a realistic view of the benefits arising from improvements in energy efficiency must read Jevons' original 1865 chapter, 'Of the economy of fuel', and should not rely solely on subsequent secondary summaries, even this one, which cannot do justice to the refined power of his argument.

In essence, Jevons' position is that an improvement in the efficiency of an energy conversion, a steam engine for example, makes that process more *productive* and thus makes its output *cheaper*. Consequently, demand for the output will in all probability *rise*. Efficiency thus creates the conditions for increased consumption.

But Jevons goes further. He sees improvements in efficiency and thus productivity as the fundamental cause of the observed growth in wealth and in energy consumption over human history:

> It needs but little reflection, indeed, to see that the whole of our present vast industrial system, and its consequent consumption of coal, has chiefly arisen from successive measures of economy.

Paraphrasing the German chemist Liebig's profound and parallel observations to the effect that 'Civilisation […] is the *economy of power*', Jevons continues:

> It is the very economy of the use of coal that makes our industry what it is, and the more we render it efficient and economical, the more will our industry thrive, and our works of civilization grow.[15]

As processes become more productive they are typically used more, and even if demand is temporarily inelastic in that area, any energy conserved is 'only saved from one use to be employed in others' (p.115). There is no principled

limit to the changes that human beings will make to the world to serve their interests, and consequently energy is like cash and never, ever left on the table. No woman, no sane man will ever say, for example, that child mortality is low enough.

Further, Jevons' position is not theoretical only, as is often supposed by later writers. His thinking is empirically grounded in a deep understanding both of economic history and the evident growth of human wealth. Both of these bodies of data and argument show that it is naïve to expect improvement in the efficiency of conversion devices to reduce total, absolute energy demand:

> […] if economy in the past has been the main source of our progress and growing consumption of coal, the same effect will follow from the same cause in the future. Economy [i.e. efficiency] multiplies the value and efficiency of our chief material; it indefinitely increases our wealth and means of subsistence, and leads to an extension of our population, works, and commerce […]

There is nothing in subsequent history to suggest that he is mistaken. At every point in our economic development we observe improvements in the efficiency of conversion processes and increases in overall energy consumption. Further improvements in energy efficiency are immensely desirable, for they will bring great benefits to humanity, as they have done in the past, and there is every reason to expect them to continue to be a focus of invention and innovation. They will increase our wealth and means of subsistence; they will reduce mortality; they will spare energy from immediate consumption for longer-term capital investment ('works' as Jevons calls them), creating demand for yet more energy in order to create still greater wealth; and thus greater human liberty.

But efficiency does not and *cannot* lead to conservation. Thus the observed conservation fall or stagnation in energy consumption must result from some other cause. I suggest that in the case of the European Union, the United Kingdom, and also the United States, for which some illustrative data has been presented in this paper, it is the result of faltering economic growth caused by the systemic increase in energy costs consequent on the coerced introduction of renewables, which began in most of these areas in the later 1990s and in earnest in the early 2000s. Whether this disturbance has any explanatory role in the economic crash of 2008, which it anticipates, is uncertain, but it is likely that recovery from the crash has been inhibited by underlying energetic weakness.

Lest the connection between renewables costs and declining consumption seems super-

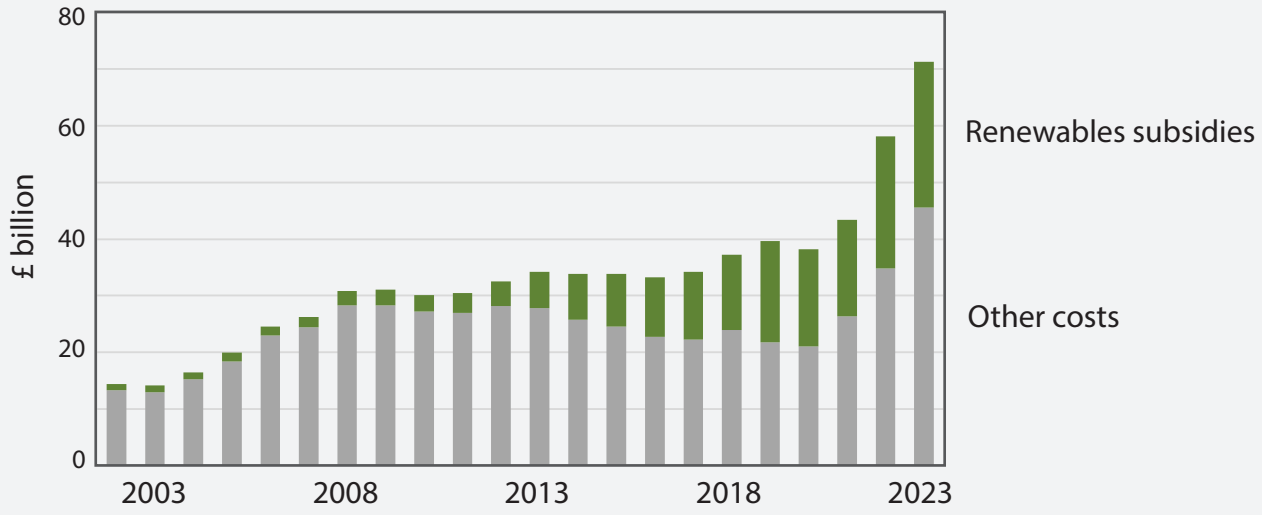


Figure 19: The cost of UK electricity supply: subsidy to renewables and other costs.

Source: Renewable Energy Foundation, 'UK Renewable Electricity Subsidy Totals: 2002 to the Present Day' (https://www.ref.org.uk)

ficially implausible it will be as well to indicate here the scale of the subsidy involved. Recent work by the UK charity the Renewable Energy Foundation, which I direct, has calculated that there are five direct and five indirect subsidies to renewable electricity generation in the United Kingdom that are quantifiable, and these currently amount to £25 billion a year, or about 40% of the total cost of electricity supply. The growth in this subsidy stream is shown in Figure 19.

The total subsidy cost over this period amounts to approximately £220 billion (in 2024 prices), and is more than adequate to generate a price-rationing effect sufficient to explain the observed decline in electricity consumption.

Conclusion

By coercing the adoption of high-entropy fuels, and by suppressing the use of low-entropy fossil fuels, policy will reverse the processes seen in the Netherlands and Britain and then the rest of the world from the late medieval period onwards, where coal and then oil and gas broadened the ecological niche and enhanced human liberty, with autocatalytic effects further increasing wealth and freedom.

That process was no overnight revolution and took several hundred years, but a decline in wealth may have different characteristics. Whereas the beneficial autocatalytic effect of human liberty on wealth creation is remarkable but moderate and slow in generating its effect, the self-poisoning that will occur as wealth is destroyed and human liberty eroded could have consequences that are rapidly manifested.

While it is true that in general we over-diagnose the existence of revolutionary transitions and discontinuities in societal affairs, we cannot deny their possibility or their factual existence, and it would be complacent to rule them out in our present case. In coercing a change of fuels against the thermodynamic gradient, forcing the use of higher-entropy sources that would be and indeed have hitherto been spontaneously rejected in a liberal market, because harmful to human welfare, it is possible that the state apparatus may trigger a discontinuity. Humanity has climbed slowly and arduously yet almost unwittingly up Mount Improbable and now enjoys remarkable prospects. But should we lose our hand- and footholds, we are all but certain to slide rapidly and with much injury down its steep and unforgiving slopes.

The first signs of this disaster will be a transfer of socio-political authority to the renewable energy sector as policy supported by state policy permits them to engross the majority of the real capital available to our society. This will result in a concentration of power and the consequent constriction of individual human freedom unseen for several hundred years. It is hard to believe that this would be a politically stable situation.

There has been undoubted progress in human affairs on the thermodynamic axis. Contemporary human societies, the global population and society considered as a whole, is without any question much further from equilibrium than those living 10,000 years ago, or even as recently as 1600. That expansion of the ecological niche has delivered a notable improvement in human freedom and in moral tolerance. We are not only able to live but willing to let live. This state of affairs is exceedingly improbable. There are already signs that this extraordinary interlude, which began only three or four hundred years ago, is drawing to a close in the West. The East, on the other hand, is a different matter, as it always has been.

Endnotes

1. Attributed to François Quesnay in a letter from M. Alpha to Quesnay, 1767, in L. Salleron, *François Quesnay et la Physiocratie* (1958), Vol 2, 940. However, the Oxford Dictionary of Quotations (Oxford: 1996) reports that the words are not found in Quesnay's writing.
2. *Shorter Oxford English Dictionary* (Clarendon Press: Oxford, [1933] 1965).
3. G. Lemaître, 'The Primaeval Atom Hypothesis and the problems of clusters of galaxies', in R. Stoops, ed., *La Structure et l'Evolution d l'Univers* (Brussels, 1958), 1–25.
4. Arnold Toynbee, *Lectures on the Industrial Revolution in England: Popular Addresses, Notes and other Fragments* (Rivingtons: London, 1884).
5. Harold Williams, ed., *The Correspondence of Jonathan Swift,* Vol. II, *1714–1723* (Clarendon Press: Oxford, 1963), 372–373.
6. E. A. Wrigley *Energy and the English Industrial Revolution* (Cambridge UP, Cambridge, 2011), 196.
7. Wrigley (2011), 197.
8. See H. S. Maine, *Ancient Law* (John Murray: London, 1906 [1861]).
9. Thomas De Quincey, 'The English Mail Coach' [1849], in John Jordan, ed., Thomas De Quincey, *The English Mail Coach: And other Essays* (Dent: London, 1961), 1–46.
10. Bernard Mandeville, *Fable of the Bees*, ed. F. B. Kaye (Clarendon Press: Oxford, 1924[1729]), Vol 2, 141–142.
11. Andrew Lambert, *Seapower States* (Yale UP: New Haven and London, 2018), 239.
12. Lord Chesterfield, to his son, 25 December 1753, in R.K. Root, ed., *Lord Chesterfield's Letters to His Son* (Dent: London, 1929), 275.
13. Friedrich List, trans. Sampson S. Lloyd, *The National System of Political Economy* (Longmans: London, 1922 [first printed 1885]).
14. W. S. Jevons, *The Coal Question* (Macmillan: London, 1865), 103.
15. *Coal Question* (1865), p.105. Liebig's remark appears in Justus von Liebig, *Familiar Letters on Chemistry* (Taylor, Walton, & Maberly: London, 1851), 462, and reads 'Cultivation is the economy of force. Science teaches us the simplest means of obtaining the *greatest* effect with the *smallest* expenditure of power, and with given means to produce a maximum force.'

The Net Zero and Liberty project

This paper is the first publication in our series *Net Zero and Liberty*, which seeks to explain the dedevelopment of political and economic liberty in the west has been inextricably linked to energy, and how decarbonisation policies threaten to erode many of our hard-won freedoms.

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